

Data acquisition system based on fast waveform digitizers for large neutrino detectors

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Abstract. For large volume neutrino and antineutrino detectors it is crucial to have an efficient data acquisition system capable of digitizing data from thousands of detection channels. Here we present a flexible DAQ system architecture consisting of a large number of fast waveform digitizers and configurable FPGA-based trigger logic. The current implementation of the system is functioning in the Borexino neutrino detector providing zero dead time spectroscopy data in the energy range from 1 up to 100 MeV. Acquisition complex in combination with our custom analysis software is successfully being used for registration of geoneutrinos, as well as search for neutrino signal from GRBs, solar neutrino spectroscopy and other applications.

1. Introduction

In this work we present a DAQ complex based on flash ADCs (also called fast waveform digitizers, FWFs) used to digitize signal waveforms. The complex also includes programmable discriminator and programmable logic unit for trigger processing. Such system could be used for data acquisition as a part of different particle physics detectors. System architecture allows to simultaneously process data from more than 100 individual channels and enables a possibility to use a complex data acquisition control logic. Currently the system described is implemented in Borexino detector and provides neutrino and antineutrino spectroscopy in energy range from 1 up to 100 MeV.

Borexino is an ultra low background neutrino scintillation detector located in underground Laboratori Nazionali del Gran Sasso (Italy) on the depth of 3800 mwe. Detector target is a nylon sphere 4.25 m in radius containing 278 tons of pseudocumene-based liquid organic scintillator. Around the target lies concentric spherical 6.25 m buffer volume filled with dimethylphthalate doped pseudocumene buffer liquid. Scintillation light in the target and the buffer is registered by 2212 low background PMTs. Spheres are contained inside 2100 m³ water tank (called outer detector, OD) used to shield the target from external radiation and provide a muon veto by means of additional 208 PMTs [1].

The primary Borexino task is a low energy neutrino spectroscopy [2] in sub-MeV range, which led to main data acquisition system based on spectroscopic ADCs been optimized for low energy range and unable to measure events energy above 15 MeV with high accuracy. But to allow study of rare events above 15 MeV of astrophysical neutrino origin, such as supernova neutrinos, DSNB neutrinos, GRB-correlated neutrino flux and others, an additional DAQ system



to enable spectroscopy in the higher energy range was required. To address this requirement a FWFD-based DAQ system described in this work was introduced into Borexino alongside the main one. Here we will base our description mainly on Borexino implementation. Nevertheless, it should be noted that DAQ system architecture was developed to be flexible enough not to be limited to Borexino FWFD subsystem, but could be used for different detectors with large number of acquisition channels. Currently the next implementation of this trigger and DAQ architecture based on newer hardware is being adopted in iDREAM detector for remote neutrino reactor monitoring[3].

2. Borexino FWFD-based DAQ system structure

The main requirements for Borexino high energy DAQ were to provide zero dead time spectroscopy of events with energies up to 50-100 MeV with maximum possible independence of main DAQ. Borexino FWFD-based DAQ system is installed into 4 VME crates with unified address space and consists of (figure 1):

- Analog circuits for PMT signal summing
- 34 VME ADCs with three 400 MHz 8-bit channels each (CAEN V896)
- FPGA-based trigger module with VME-interface
- Clock and trigger distributors
- 16 channel constant fraction VME programmable discriminator (CAEN V812)
- VME single-board control computer

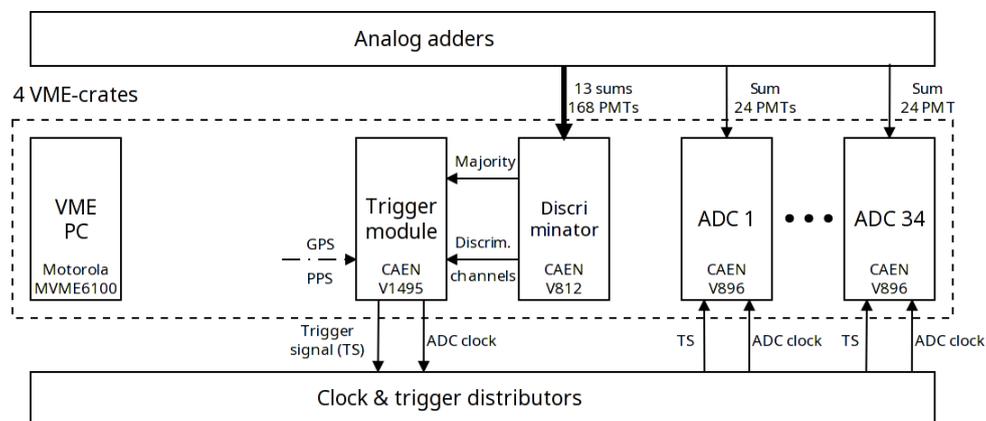


Figure 1. General Borexino FWFD-based DAQ system scheme.

The signal from PMTs comes to the FWFD system via Borexino front end electronic boards common to all Borexino DAQ systems. Front end boards (FEB) provide PMT signal amplification and first stage signal sum of up to 12 PMTs per board. FWFD-system second stage analog summing boards provide separate sums of 2 FEBs, of 14 FEBs and of all detector PMTs. Twofold sums and full detector sum are digitized by individual ADC channels and sums of 14 FEBs are used as discriminator inputs [1].

Usage of fast ADCs to digitize signals from scintillation neutrino detector provide several benefits in comparison to classical spectroscopy ADCs. It allows to eliminate dead time and analyze waveform shape and pulse edges. Flash ADCs used in the FWFD system continuously digitize the input signal to an internal memory buffer and immediately switch to next buffer when the trigger signal arrives. This allows zero-dead time PMT signal acquisition crucial

for rare event studies. All 34 VME ADC modules are synchronized by the clock and trigger signals distribution modules which are used to ensure digitization clock phase alignment and simultaneous trigger signal edge. Each ADC module consists of 3 independent 400 MHz 8-bit ADC channels, giving a total of 102 digitization channels. 91 partial detector sum, 2 full detector sums with different amplification and 1 outer detector sum is being digitized, several remaining channels are a hot spare.

As a main trigger source 13 sums of 14 FEBs are connected to inputs of 16 channel constant fraction discriminator with VME interface. Discriminator uses a majority logics, it provides a majority output if several input channels are simultaneously above threshold. Per channel thresholds and majority level are set from DAQ control software running on the control computer with remote access [4].

3. Versatile trigger logic

Central part of the described DAQ system is a versatile trigger module. Trigger module is used to produce a trigger signal on useful detector events and suppress trigger when digitization is not desirable for some reason. Also trigger module allows to store an information about produced trigger and provides an additional functionality such as different event rates counting and estimation of dead time due to external inhibits. To allow maximum performance and flexibility the trigger module is based on FPGA (field programmable gate array) reconfigurable logic chip. Trigger functionality is provided by programming this FPGA chip. FPGA and trigger configuration should be accessible from the control computer, for Borexino implementation the VME-bus was used for these means. Internal trigger layout is present in the figure 2. Trigger module consists of following main blocks all realized inside the FPGA firmware:

- Trigger production unit.
- Trigger info storage unit (FIFO).
- Rate counters and dead time timers.
- GPS time unit.

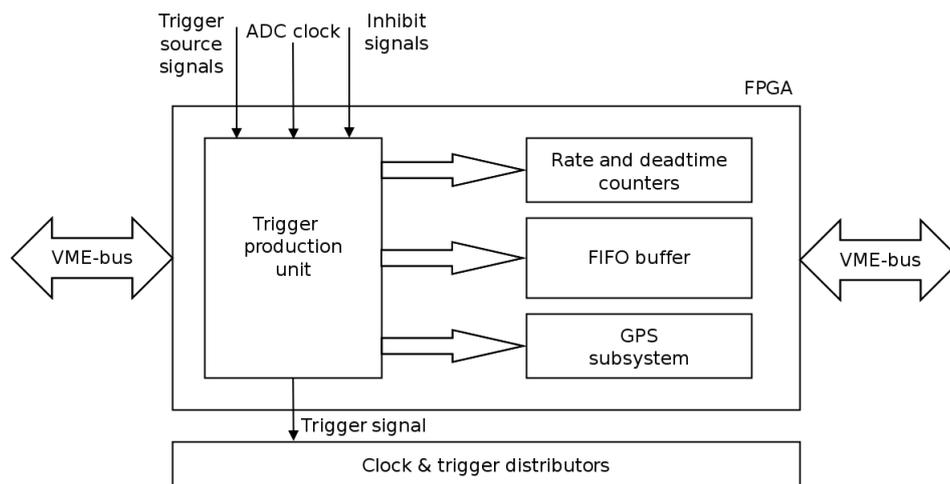


Figure 2. Trigger unit block diagram.

To achieve maximum versatility, the FPGA trigger firmware was programmed in the way to allow adjustment of all submodules parameters via VME-bus registers without firmware reload. Also FPGA firmware itself could be updated from control computer via VME.

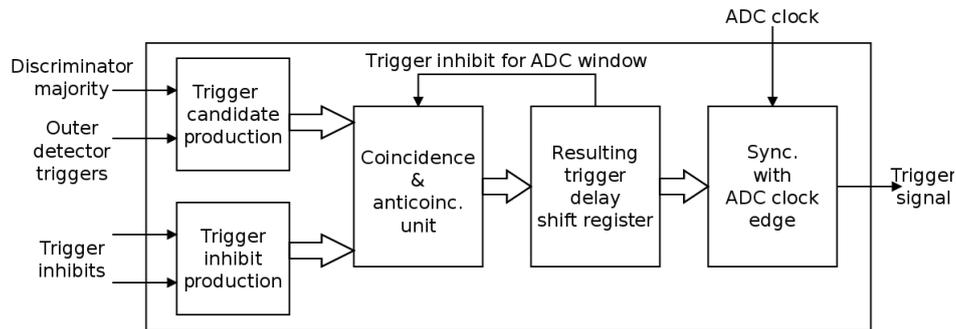


Figure 3. Trigger production logic.

The main integral part of the trigger system is the trigger production unit (figure 3). It produces triggers based on up to 8 trigger inputs in anticoincidence with up to 8 inhibits. Coincidence and anticoincidence time windows and delays for each input along with the additional trigger candidate and inhibit parameters are adjustable on run time. By changing coincidence parameters and signal delays to match processes inside detector it is possible to tune the system for a wide variety of physical tasks. In Borexino trigger sources are a signal from majority discriminator and two different OD triggers. The inhibits are several calibration triggers and noise suppression system output, which are used to reduce undesirable event rate. Also trigger system denies triggers for a configurable time, which is set to be a bit shorter than ADC time window cause it's possible to have several physical events in one ADC window or in nearby windows (in last case windows are "glued" together by analysis software). After trigger passes through coincidence logic, it is delayed on shift register to allow ADCs to fill the time window after the trigger. Several triggers could be processed simultaneously. Information about each produced trigger such as trigger source, GPS time and other flags is stored in buffer (FIFO) size of which is set to match the size of ADC event buffer. FIFO buffer is meant to be read by DAQ software on the control computer to get info about occurred events.

Ease of FPGA reconfiguration also allows to realise additional functionality required for particular setup. In Borexino FWFD system trigger unit is used to produce GPS time tags from precise PPS (pulse per second) signal and to save data from main DAQ trigger system to perform event correlation between two systems later in software. Also rate of all produced trigger types, trigger sources and trigger inhibits is counted and is made accessible via VME registers to allow online monitoring at DAQ time.

4. Conclusion

We've presented a DAQ system architecture built on fast waveform digitizers and FPGA-based trigger. This system is capable of processing data from particle physics detectors with large number of channels and currently provides data for rare neutrino event analysis in Borexino detector and is being integrated into new iDream detector.

Acknowledgments

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References

- [1] Alimonti G *et al.* 2009 *Nucl. Instr. and Meth. A* **600** 568-93

- [2] Arpesella C *et al.* 2008 *Phys. Lett. B* **658** 101-8
- [3] Gromov M *et al.* 2015 *Moscow University Physics Bulletin* **70** 190-4
- [4] Litvinovich E *et al.* 2013 (in Russian) *Preprint IAE-6756/2* (original Russian title: Sistema sbora dannih na osnove bistrih ocifrovshikov formi impulsa)